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(56) Documents Cited
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WO 89/01760 A1 WO 87/00026 A1 WO 81/01506 A1
US 4774679 A US 4665928 A

(58) Field of Search
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(54) Abstract Title
Monitoring of biomechanical load variables on a freely moving test person

(57) A method of monitoring biomechanical load variables on a freely moving test person, is characterised by the following steps:

Measuring time characteristics of body angles, including knee angle, hip angle and torso angle with trunk twisted, lateral flexion and large flexions in the region of the thoracic and lumbar spine on a freely moving test person during a physical activity;

Measuring ground reaction forces and points of force application to the test person;

Determining threshold values for the identification of postures and comparison of such threshold values with the measured angles to identify motion patterns;

Calculating the expected total ground reaction force based on the measured body angles together with the corresponding anthropometric data and subtraction of the expected total ground reaction force from the actual measured total ground reaction force to determine externally exerted forces;

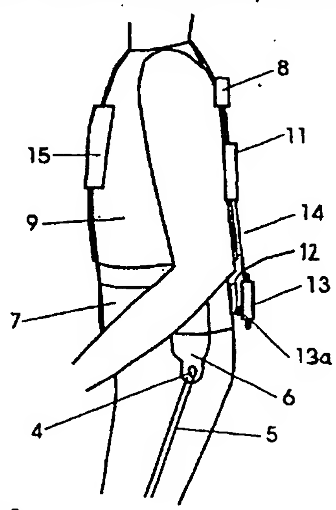

Fig. 3

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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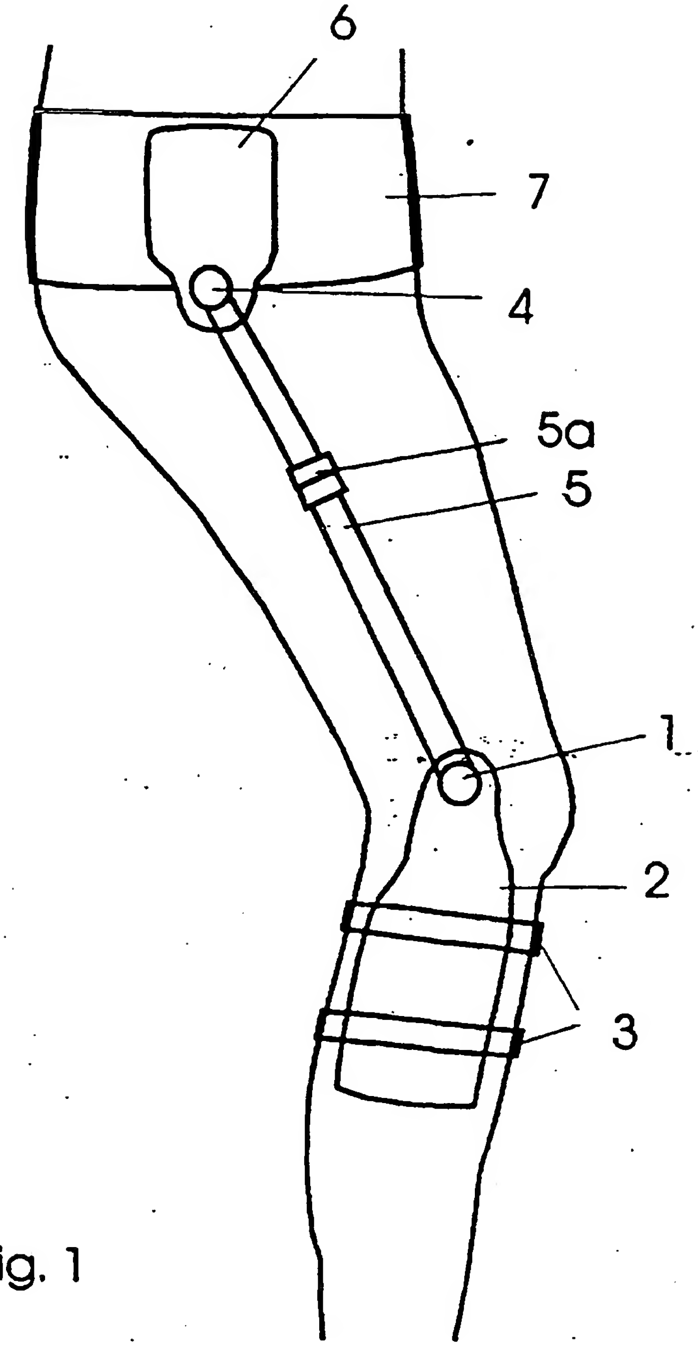


Fig. 1

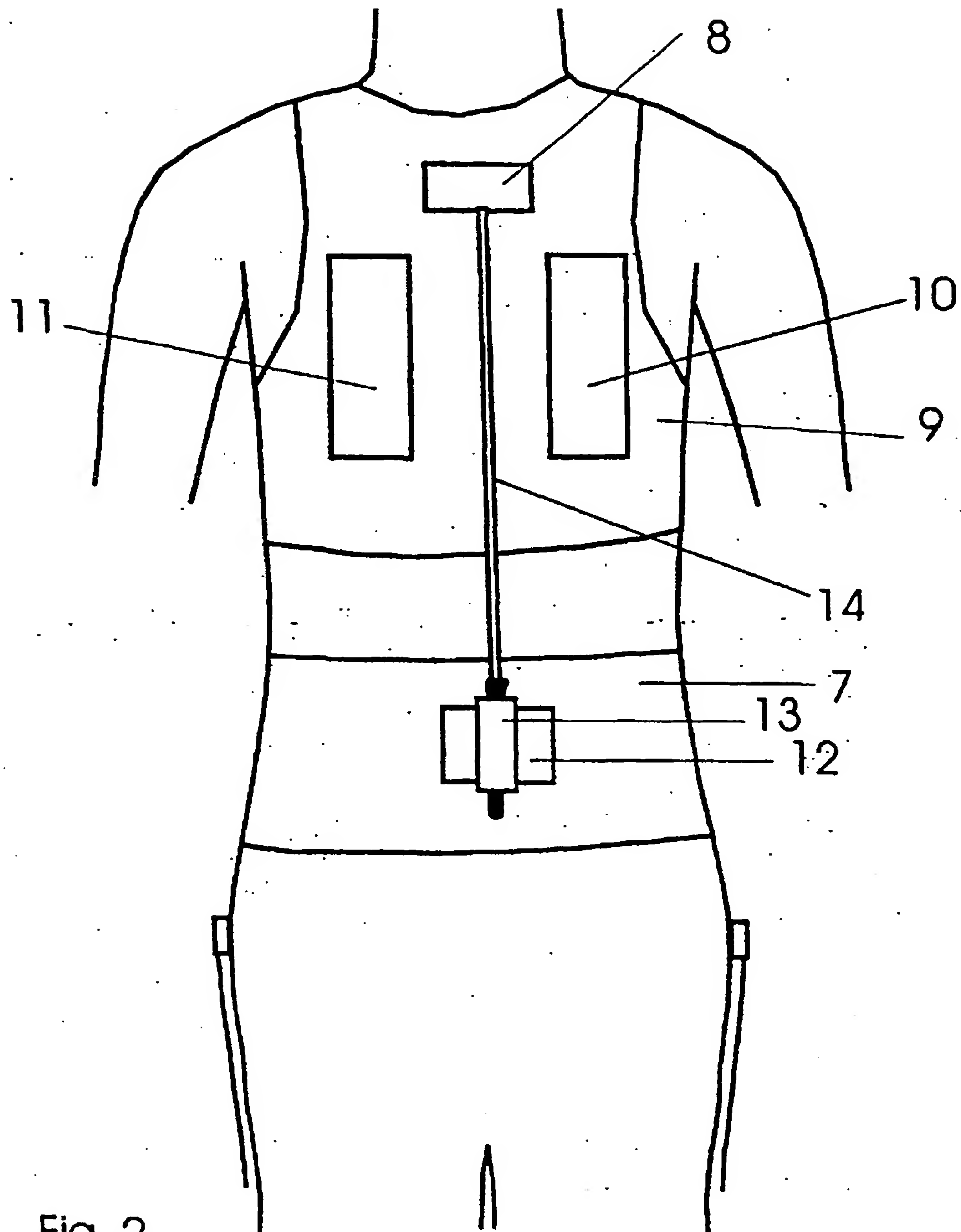


Fig. 2

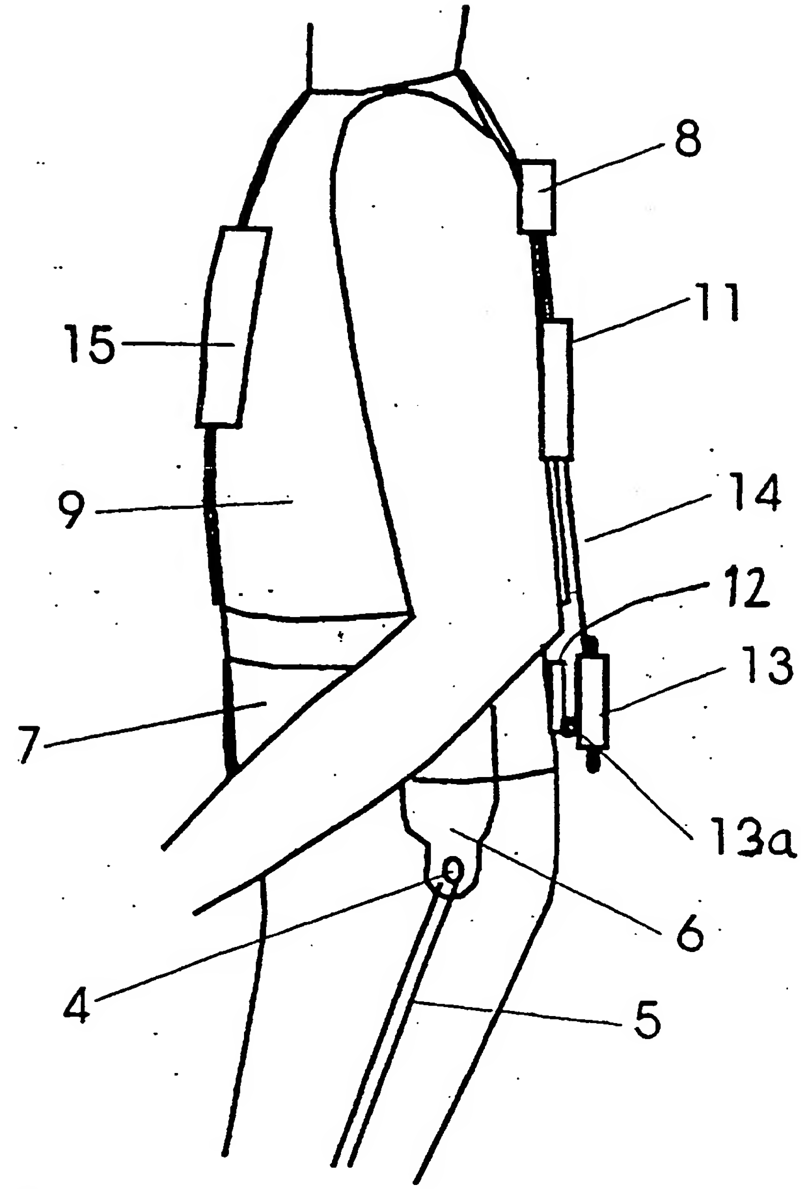


Fig. 3

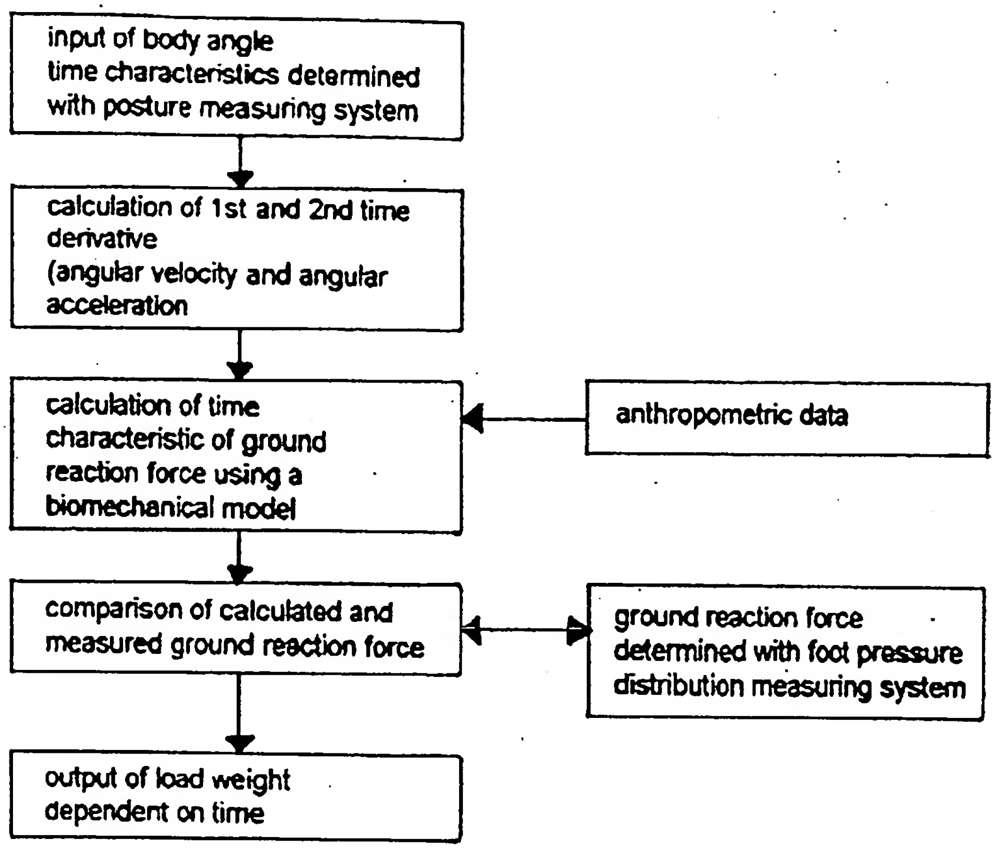

input of body angle
time characteristics determined
with posture measuring system
calculation of 1st and 2nd time
derivative
(angular velocity and angular
acceleration
calculation of time
characteristic of ground
reaction force using a
biomechanical model
anthropometric data
comparison of calculated and
measured ground reaction force
ground reaction force
determined with foot pressure
distribution measuring system
output of load weight
dependent on time

Fig. 4

Fig. 5

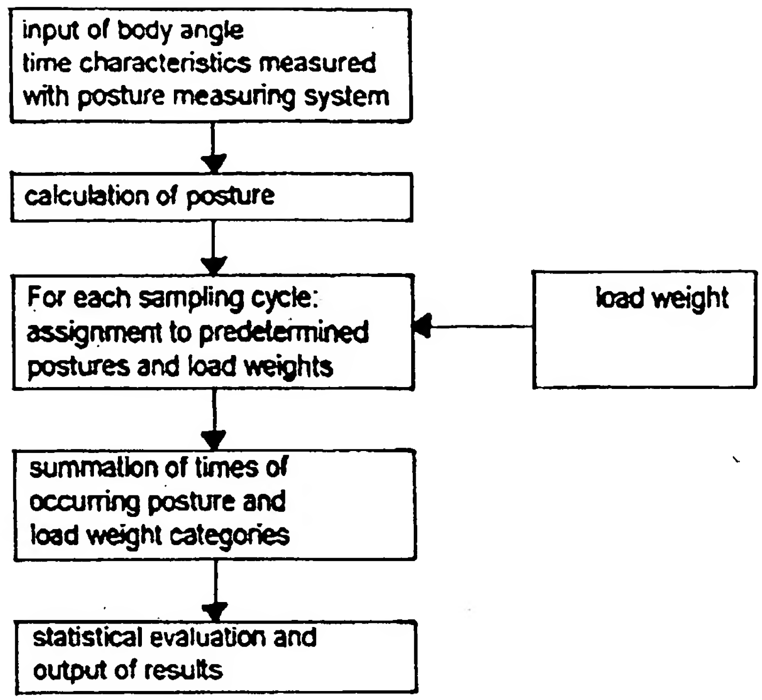

input of body angle
time characteristics measured
with posture measuring system
calculation of posture
For each sampling cycle:
assignment to predetermined
postures and load weights
load weight
summation of times of
occurring posture and
load weight categories
statistical evaluation and
output of results

Fig. 6

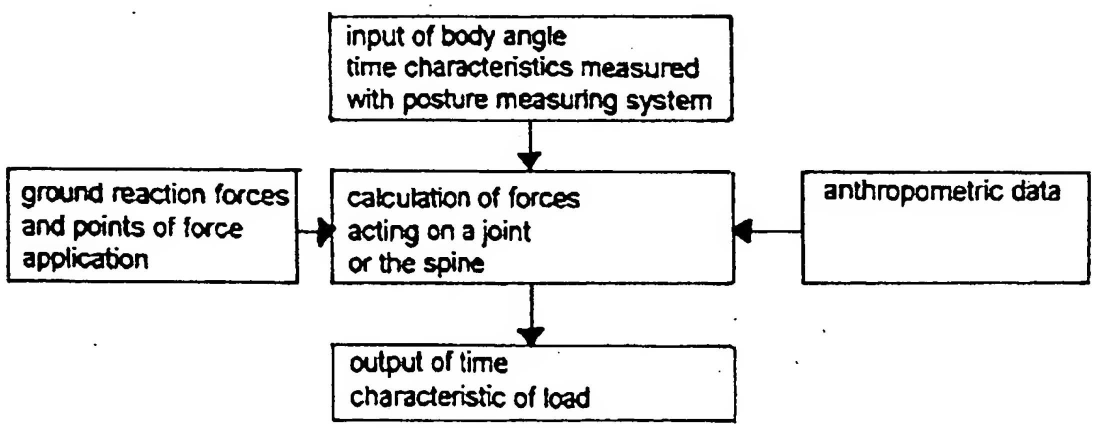

input of body angle
time characteristics measured
with posture measuring system
ground reaction forces
and points of force
application
calculation of forces
acting on a joint
or the spine
anthropometric data
output of time
characteristic of load

Fig. 7

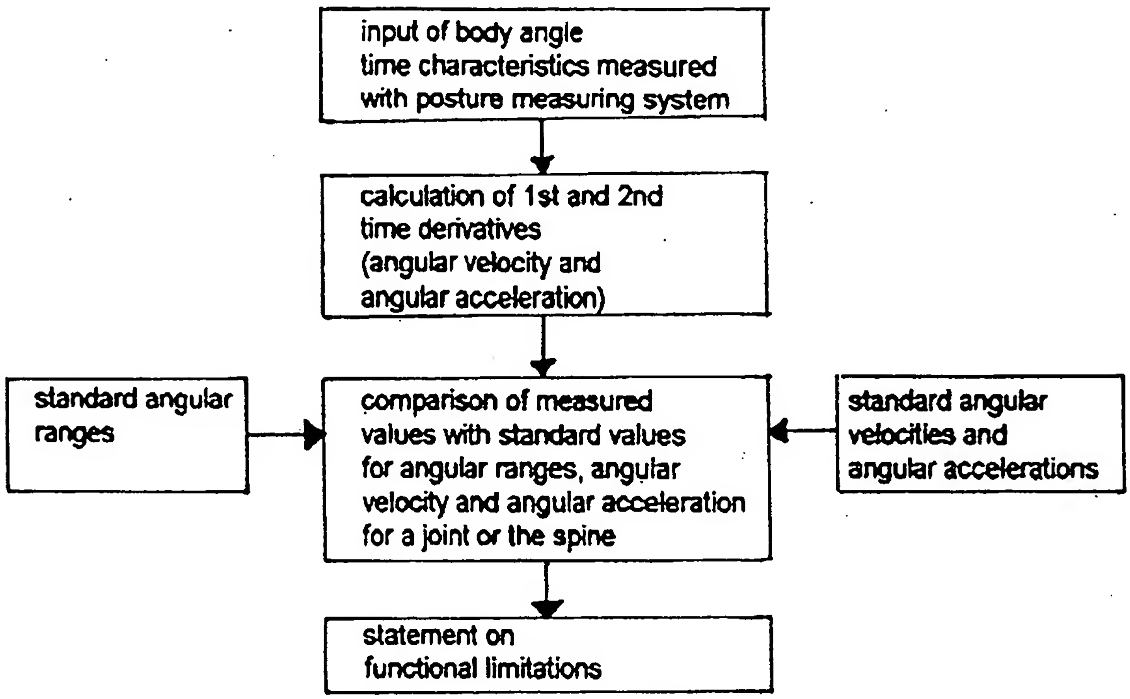
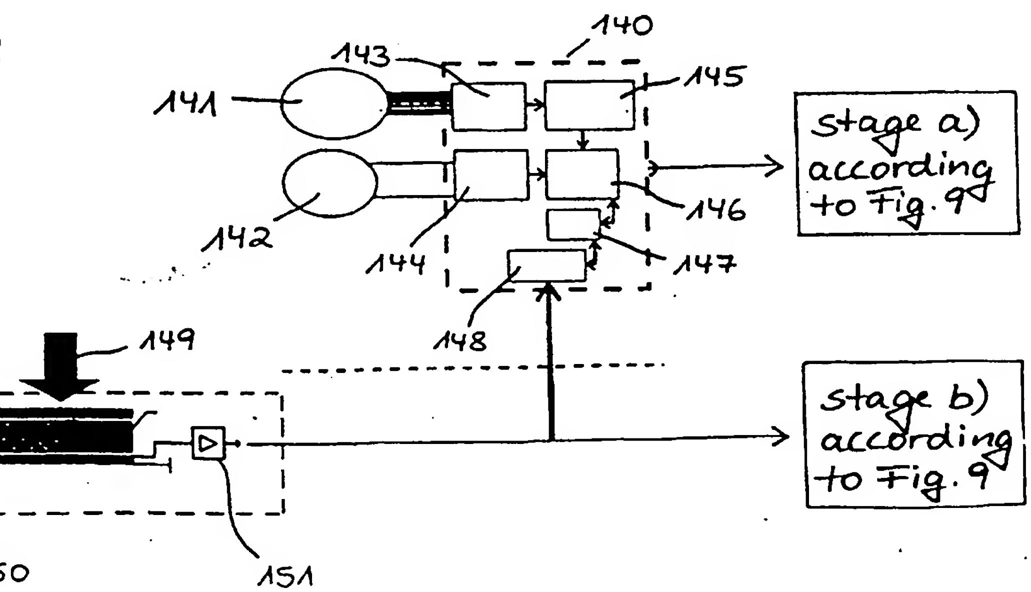

input of body angle time characteristics measured with posture measuring system
calculation of 1st and 2nd time derivatives (angular velocity and angular acceleration)
standard angular ranges
comparison of measured values with standard values for angular ranges, angular velocity and angular acceleration for a joint or the spine
standard angular velocities and angular accelerations
statement on functional limitations

Fig. 8


140
143
145
141
stage a) according to Fig. 9
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142
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147
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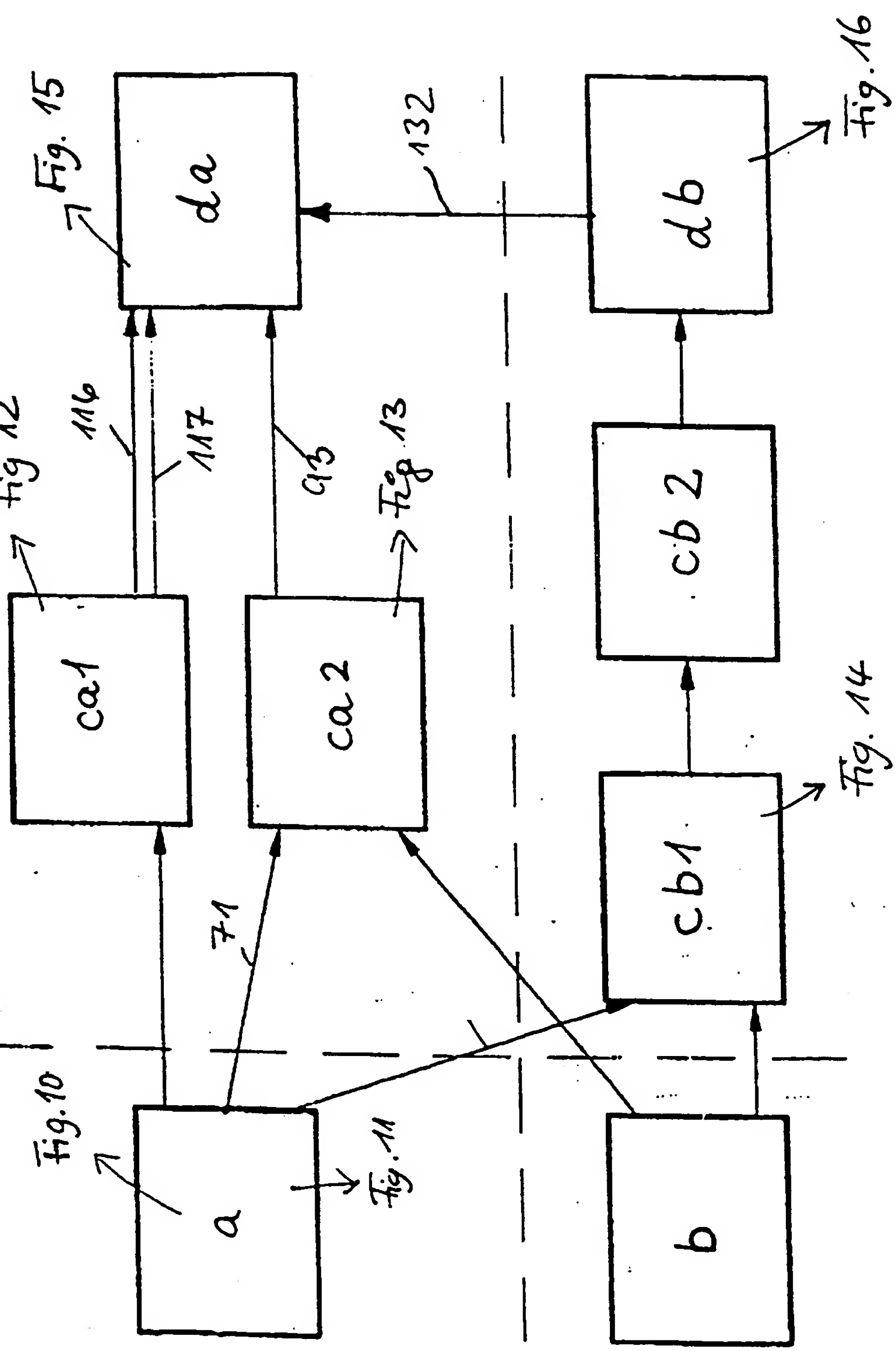
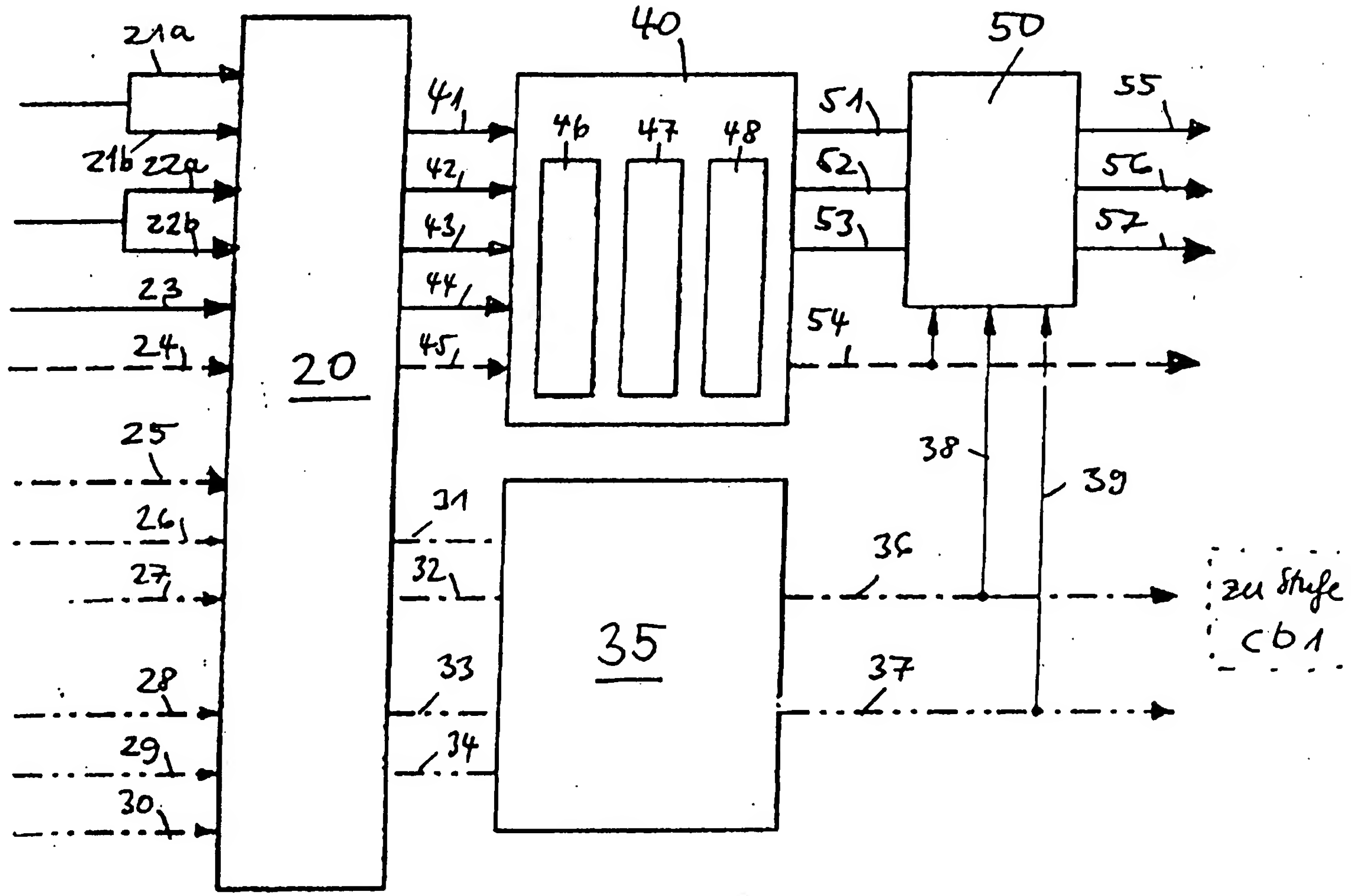
148
stage b) according to Fig. 9
150
151

Fig. 9


da
db
ca1
ca2
cb1
cb2
a
b
Fig. 15
Fig. 16
Fig 12
Fig 13
Fig. 14
Fig.10
Fig.11
116
117
93
71
132


21a
21b
22a
22b
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zu Stufe cb1

Fig. 10

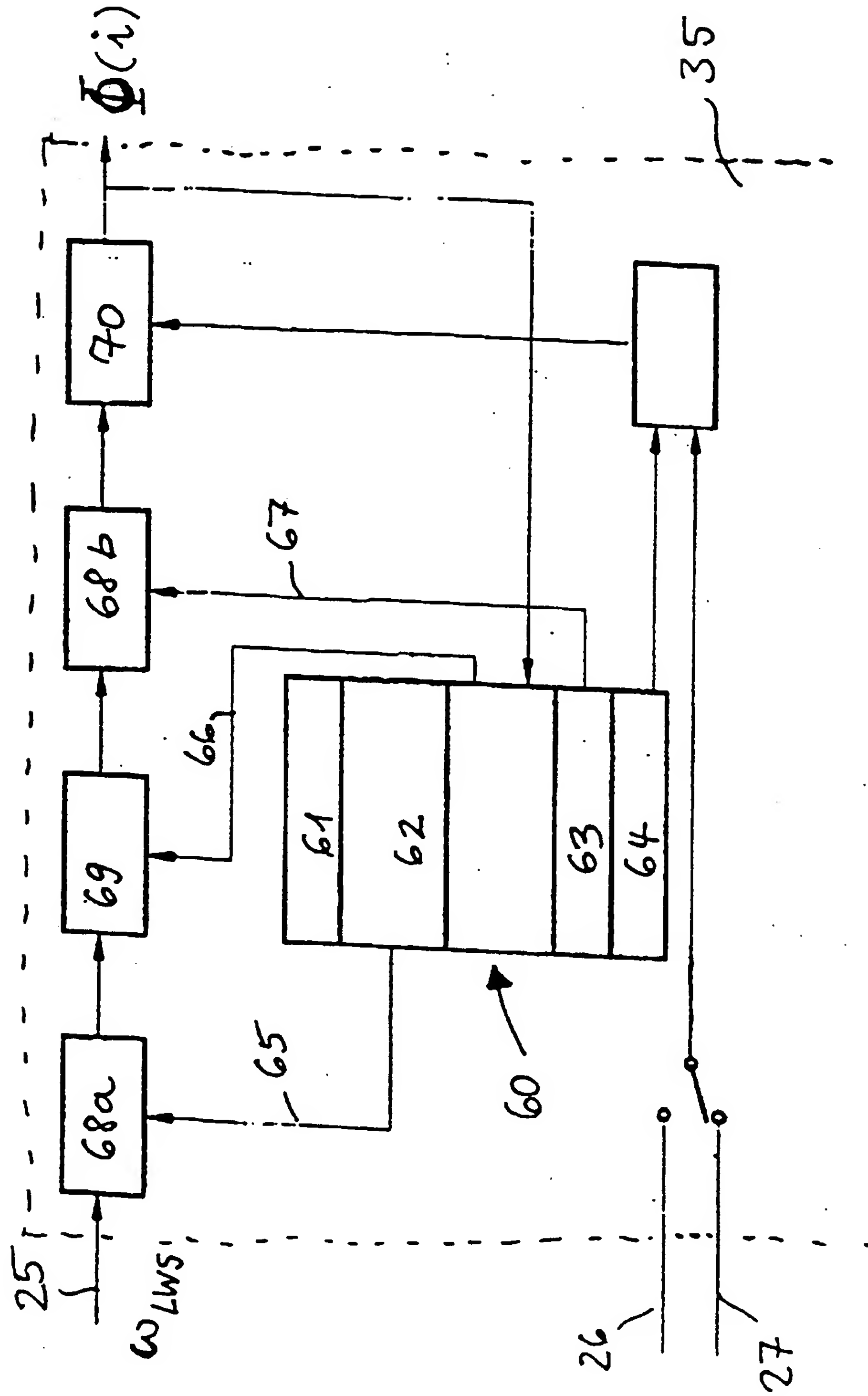

Fig. 11

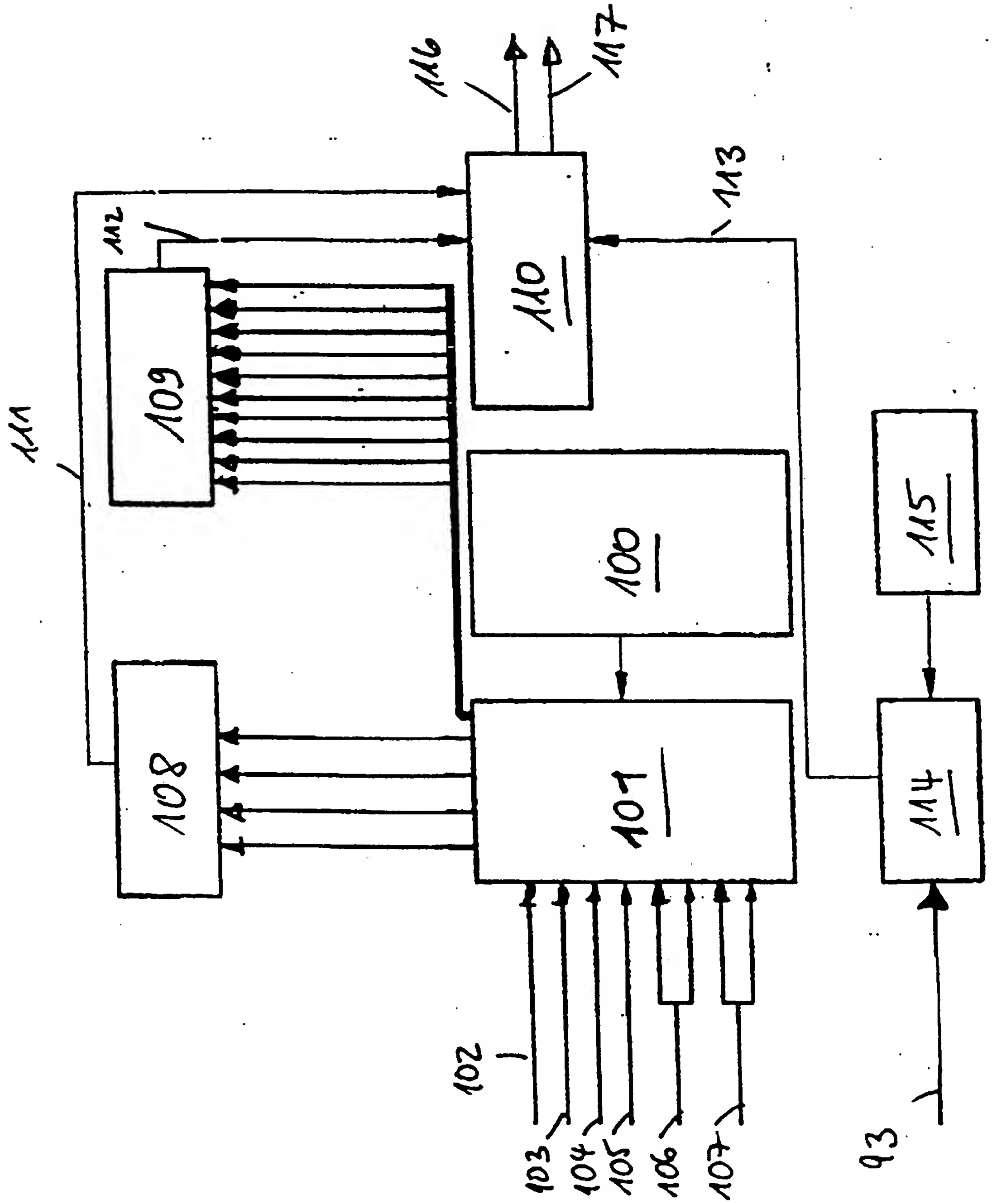

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Fig. 12

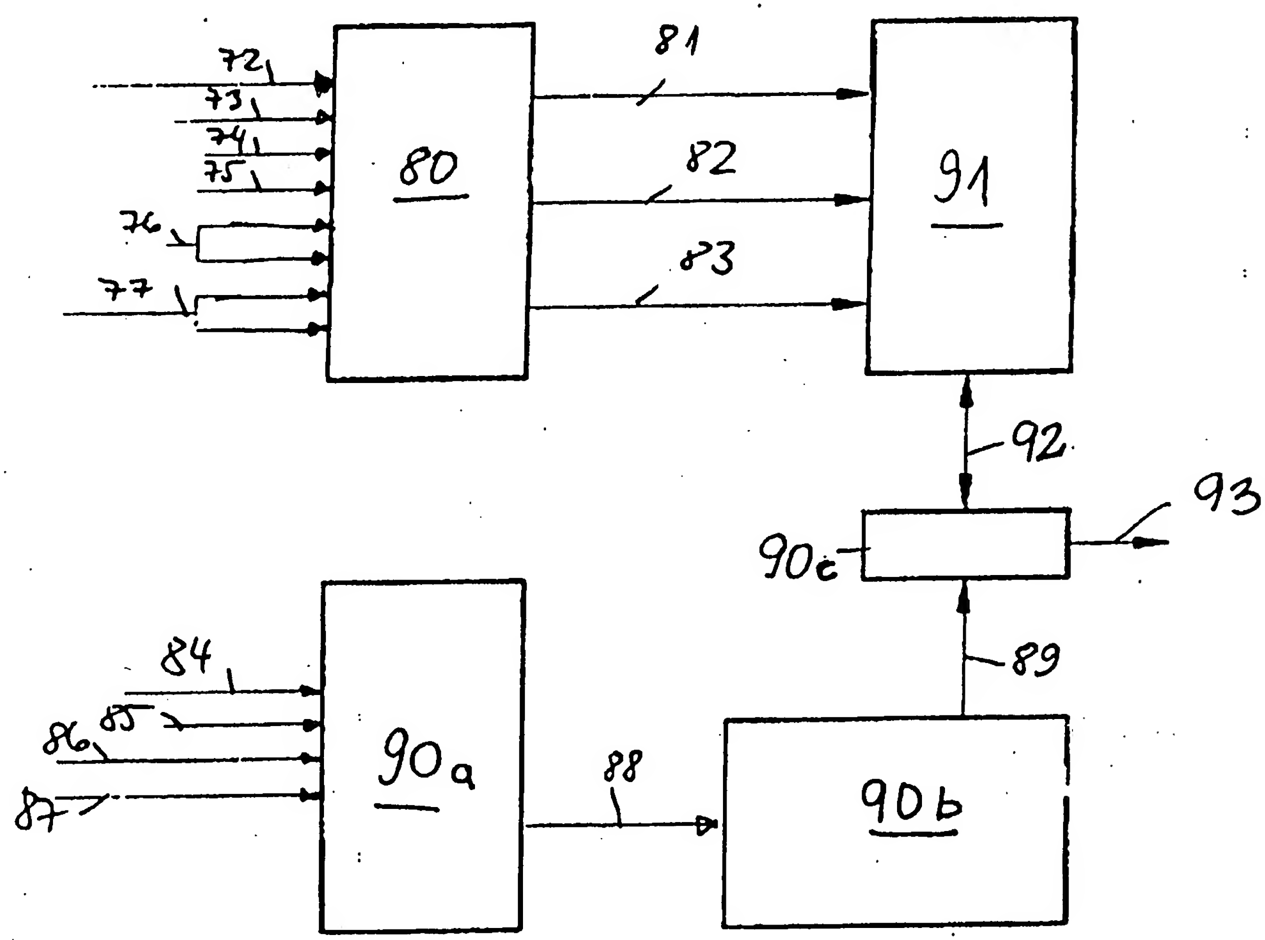


Fig. 13

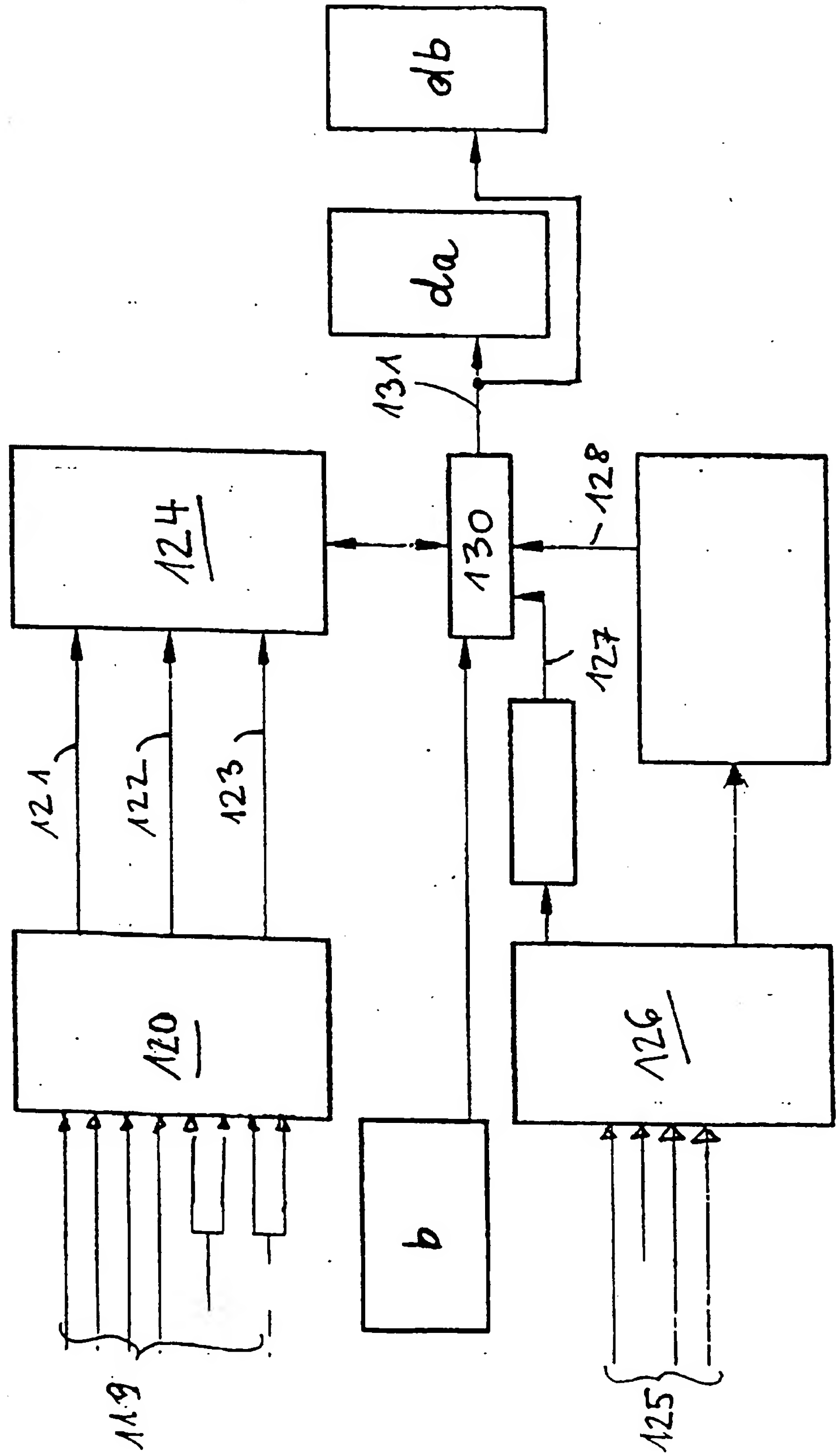
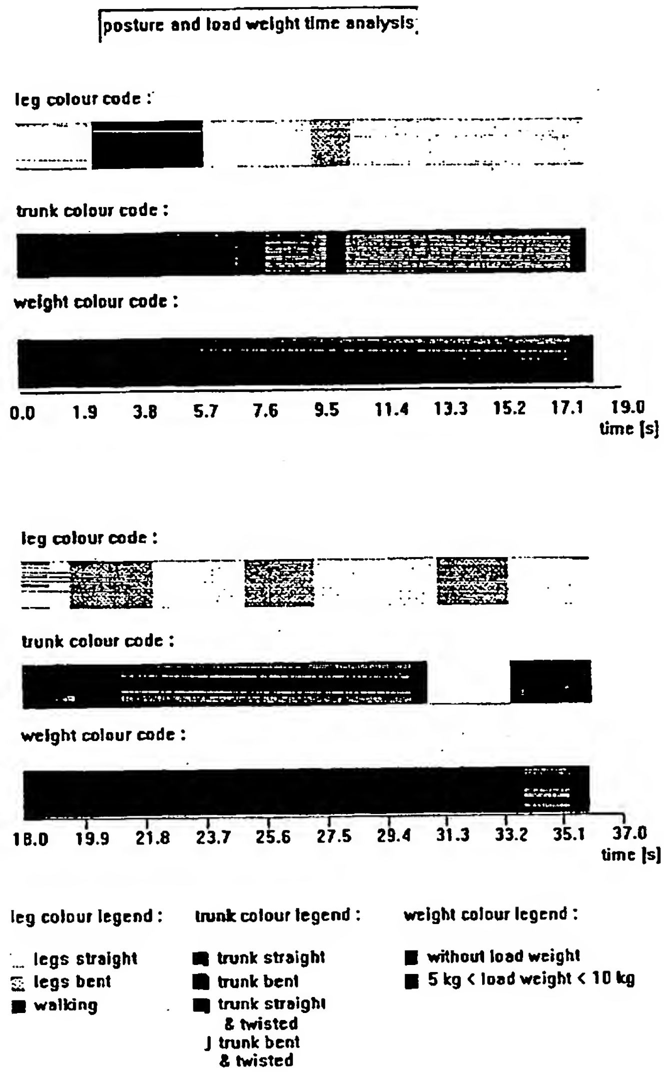


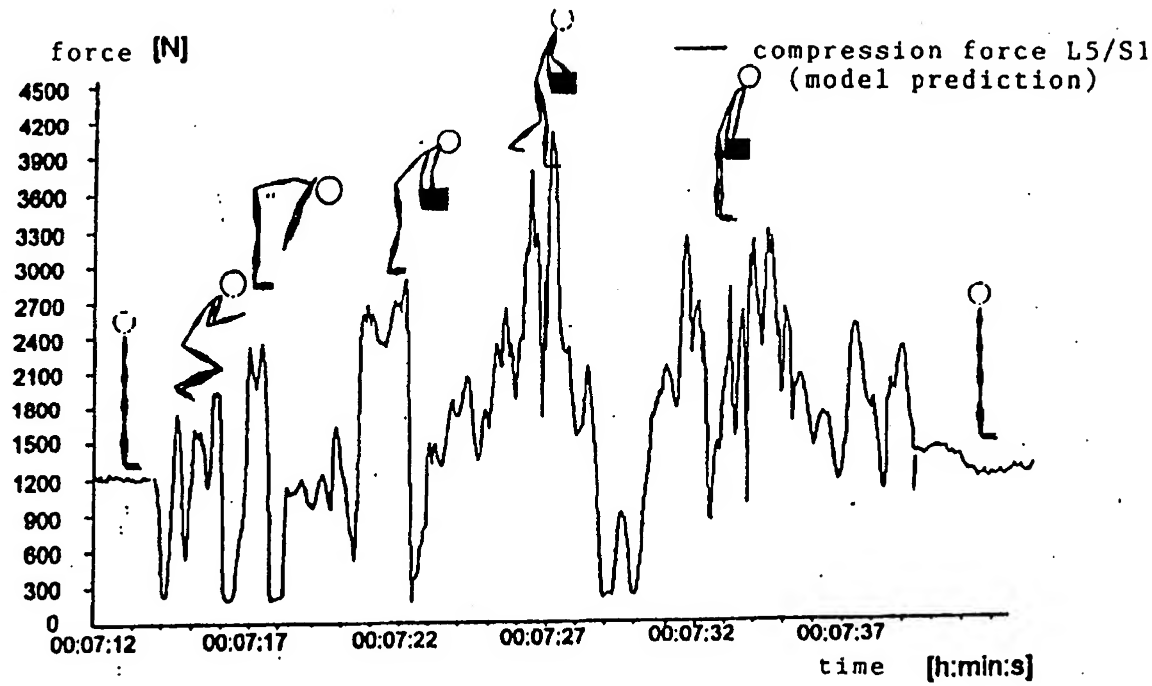
Fig. 14



beginning	end	action
0 s	2 s	standing upright
2 s	6 s	walking (5 Steps)
6 s	8 s	trunk bending
8 s	11.5 s	knee -bend
11.5 s	19 s	standing upright
19 s	23.5 s	taking load (10 kg) from the floor (leg lift)
23.5 s	26 s	standing upright with load weight
26 s	29 s	knee -bend (with 10 kg load)
29 s	30.5 s	standing upright with load weight
30.5 s	34 s	putting load on the floor (sideways)
34 s	36 s	standing upright

Fig. 15

Fig. 16


force [N]
4500
4200
3900
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
compression force L5/S1
(model prediction)
00:07:12
00:07:17
00:07:22
00:07:27
00:07:32
00:07:37
time [h:min:s]

METHOD AND SYSTEM FOR THE MONITORING OF BIOMECHANICAL LOAD VARIABLES ON A FREELY MOVING TEST PERSON

Description

The invention concerns a method for the monitoring or recording, presentation and automatic classification of biomechanical load variables measured on a freely moving test person during activity such as may be performed in a work shift, and to a monitoring system for recording biomechanical load variables.

Existing posture measuring systems only permit the determination of the movement and position of individual parts of the body. US patent 5,012,810, for example, determines movements of the spine without reference to a spatial coordinate system.

On the other hand, some systems for the prevention of job and work-related health disorders and illnesses have to be connected to external memory and evaluation units and have a power supply (see Morlock et al., 2nd Erfurt Conference, documentation of the 2nd symposium of the Erfurt Conference of the BGNG(BG for the foodstuffs and catering industry), December 1995, published by: S. Radandt, R. Grieshaber, W. Schneider, monade Verlag und Agentur, Rainer Rodewald, Leipzig 1996, pages 215 - 238, ISBN 3-00-000673-7).

Measuring systems which work with markers on the body of the person being examined and several cameras can usually only be used at workplaces

specially equipped for measurements of this kind. Their area of application is therefore very limited (see Deuretzbacher, Rehder, "Ein CAE-basierter Zugang zur dynamischen Ganzkörpermodellierung - Die Kräfte in der lumbalen Wirbelsäule beim asymmetrischen Heben", Biomedizinische Technik 40, 1995, 93 - 98).

The human spine is a double S-shaped, curved column of bone consisting of 33 to 34 vertebrae. It is divided into:

the concave (from front to back) cervical spine,
the convex (from front to back) thoracic spine,
the concave (from front to back) lumbar spine (5 lumbar vertebrae, L1 - L5),
the sacrum (5 sacral vertebrae S1 - S5),
the coccyx.

Since the lever arms of the abdominal and back muscles are very small in relation to the vertebral body or intervertebral discs (e.g. 5.5 - 7 cm for the extensors of the back), considerable muscular force is required to compensate for the resulting external torque. This in turn produces a high compression force on the discs. For example, the L5/S1 disc is subjected to a compression force of approx. 2.8 kN when a 75 kg man bends his upper body through 90° without handling a load weight. The bottom discs of the lumbar spine (L3/L4, L4/L5, L5/S1) are therefore most prone to herniation.

It can therefore be concluded that knowledge of posture and load weights handled is extremely important for assessing how dangerous an activity is for the spine.

In order to assess the biomechanical load on the musculoskeletal system, especially as a result of occupational activities, as comprehensively as possible, a method and a measuring system are required for the continual, automated recording of posture, body movements and load weights handled. This system should consist of sensors for determining the joint angles, the position of the

spine and its torsion and for measuring the ground reaction forces. It must be possible to store the signals measured by the aforementioned sensors and to present them in the form of biomechanical load variables.

A personal measuring system for recording the external load variables of occupational activities which involve the lifting and carrying of loads or which have to be performed in extreme postures should preferably meet the following desiderata:

- Trunk and leg postures should be recorded with the aid of a robust system of sensors which is easy to attach. Ground reaction forces should be recorded by a portable measuring system, synchronous with posture angle determination.

- The sensors should be attached to work clothing so that the system can be used as flexibly as possible at different workplaces. The sensors should not hinder the test person in his work.

- The measuring system should be well-suited to practical application.

- The entire measuring system (including energy supply and data memory) should be attached to the test person so that it is possible to dispense with external cable connections and so that measurements can also be recorded at workplaces where the test person has to move from one place to another.

- Data acquisition should take place with a sampling rate of at least 20 Hz. The memory of the portable data memory unit should be designed for a total measuring time of up to eight hours (one work shift).

- In order to assess the measured data, there is provision for the automated identification of classified (e.g. according to OWAS) postures once measuring has been completed. The method should be capable of being used to determine the load weights handled based on measured body angle data and

ground reaction forces. The entire evaluation process should also be fully automated.

The object of this invention therefore is to enable the collection of the data necessary for assessing the load placed on the skeleton, especially the spine, directly at the workplace, without any measuring or power supply cables getting in the way, for the duration of one work shift, to store them temporarily and to evaluate them automatically using suitable methods at the end of the shift. Using the data collected with the measuring system, dynamic processes may also be included in the load determination process for the human body in order to provide a complete picture of the nature and extent of the forces acting on a test person.

The invention solves this task with a method and a measuring system for recording and presenting biomechanical load variables in accordance with claims 1 and 16. It has been shown that by means of the system for the continual, automated recording of posture, body movement and loads handled, together with sensors used in the appropriate manner, it is possible to determine joint angles and, based on these, the position of the spine in relation to a spatial coordinate system. Using a control unit for the cycled scanning of the sensors and a memory unit for storing the signals received, plus a foot pressure distribution measuring system for determining reaction forces and the position of the idealised point of force application, the loads on the spine can be determined and evaluated according to various methods.

Using the method described in this invention, it is possible to make statements concerning the external loads on the skeleton or parts of the skeleton which occur during individual work stages. This means that activities performed can be assessed according to kind, type and biomechanical load factor in keeping with occupational needs (e.g. prevention).

The invention allows the data recorded to be stored temporarily in the measuring system on the freely moving person. This means that data collection

is not dependent on large-volume and heavy auxiliary equipment in the form of memories, computers and supply equipment. If required, data can also be evaluated directly at the workplace, as soon as measuring has been completed.

Various methods of analysing and assessing work postures are known. In connection with the method described in the invention, the OWAS method is, for example, used for assessment purposes. This is based on a data collection sheet for 84 basic work postures and three load weight classes and measures the frequency of movements of certain parts of the body in connection with load weights handled. The evaluation phase then establishes four empirically calculated load groups which result in an OWAS measures classification of each activity examined for the purpose of prevention. This method of determining work postures which strain the body is applied with the aim of preventing a harmful excessive or abnormal load from being placed on the supporting/locomotor system, e.g. by restructuring the workplace and/or modifying work organisation.

Current data collection, posture and load weight identification methods are extremely time-consuming and labour-intensive, and only static postures are recorded. However, in order to assess work-related vertebral loads, information on body movement, load duration and velocity is particularly important.

The invention is explained in further detail below, with several examples of its implementation.

In the drawings, there is shown:

Fig. 1 the attachment of knee and hip angle sensors including a connection adjustable in length which compensates for all compensating movements between knee and hip joint,

Fig. 2 the attachment of sensors for determining the position of the spine including a length-adjustment guide for the torsion actuator, controller and memory units for the posture and ground reaction force measuring system,

Fig. 3 the attachment of the energy supply sources,

Fig. 4 a flow diagram for determining externally exerted forces (load weights),

Fig. 5 a flow diagram for assigning measured postures and load weights to predetermined postures and weights,

Fig. 6 a flow diagram for determining the load on a joint or a point of the spine with the aid of a dynamic model of the body,

Fig. 7 a flow diagram for comparing measured chronological and spatial motion sequences with standard values,

Fig. 8 block diagram of a circuit arrangement for recording and processing measured data,

Fig. 9 overview of the method for the recording, presentation, automatic classification and assessment of biomechanical load variables,

Fig. 10 schematic representation of signal conditioning,

Fig. 11 schematic representation of the operating principle of the signal mixer,

Fig. 12 schematic representation of the principle for determining threshold values and for the output of the load profile in the form of motion patterns and externally exerted forces,

Fig. 13 schematic representation of the predicted total ground reaction force based on the body angles,

Fig. 14 schematic representation for determining compression force, e.g. in the lumbar spine region,

Fig. 15 sample extract from a load profile (corresponding to da in accordance with Fig. 9). The sequence of motions took place in accordance with an OWAS colour bar representation with corresponding interpretation.

Fig. 16 example of the time characteristic of predicted L5/S1 disc compression forces (corresponding to db in accordance with Fig. 9) and a representation of the assessment procedure in the form of a "vector man".

Figure 1 illustrates the attachment of the knee and hip angle sensors. The sensors 1 for the knee angles are mounted on the rails 2 which are adjusted in shape to fit the low leg and attached with Velcro strips 3 to the lower

leg over the clothing. Flexible, telescopic hip-knee connections, which can be adjusted to the length of the thigh and are easily detached at a quick-release catch 5a, are used to set both the knee angle sensors 1 and the hip angle sensors 4. The hip angle sensors 4 are fitted to moulded plates 6 which are attached to the hip belt 7, which can be adjusted to fit the wearer's hips, e.g. by a Velcro strip.

Particular importance is attached to the fact that no sensors are fitted to the thigh as there is a very great risk that muscular movements will cause any sensors attached here to slip. The flexible, length-adjustable hip-knee connections 5 compensate for any compensating movements between knee and hip joint and the pivot point of the sensor 1 remains exactly above the knee pivot.

Figure 2 shows the attachment of the sensor unit 8, which records the sensors for flexion and lateral flexion in the region of the thoracic vertebrae and torsion of the spine, to the sturdy, breathable jacket 9. The controller and memory units 10 and 11 for the posture measuring system and the ground reaction force measuring system are also attached to the jacket 9. The sensor unit 12 is attached to the hip belt 7. A torsion-proof guide 13 for the flexible actuator 14 of the torsion sensor is also attached to this sensor unit 12. The flexible wave of the torsion measuring unit 14 passes into a square metal bar 14a which is pushed into a guide 13 where it remains movable in a vertical direction. The torsion meter guide 13 is connected to the sensor box 12 via a hinged joint 13a.

The lower sensor box 12 contains the sensors for measuring trunk flexion (lumbar spine region) and connections for the leg angle potentiometers.

The sensor unit 8 contains two inclinometers with consecutive measuring ranges so that an angular range of more than 180° can be covered. The data measured by the sensors are read out at a sampling rate of 20 - 50 Hz so that dynamic processes can also be recorded. They are stored on an easily

exchangeable memory with sufficient capacity for storing all the data from one work shift (e.g. flash cards).

The sensors for determining the inclination of lumbar and thoracic spine consist preferably of one gyroscope and two inclinometers whose signals are stored separately and combined during evaluation to unite the advantages of gyroscopes - suitable dynamic behaviour - with those of inclinometers - absolute measurement of angles against the vertical axis.

Additional measuring instruments such as potentiometers, goniometers etc. can be attached for determining the position of other joints, e.g. arms.

Figure 3 shows the attachment of the energy supply source(s) 15 to the jacket 9 and the attachment of the sensor units 8 and 12 and the controller unit 11 from the side. According to the invention, the parts of the measuring system can be fitted to the test person's chest and back so that there is an even distribution of weight.

This leaves the attachment of a microcontroller for measuring ground reaction forces and an evaluation unit in which the measured data are converted into absolute spatial coordinates and assigned to posture classes.

The basic structure for a data collection unit of this kind is illustrated in Figure 8. The following applies:

140 microcontroller (80517),
141 analog sensors,
142 digital sensor,
143 multiplexer,
144 IC counter,
145 analog-to-digital converter
146 port,
147 CPU,
148 timer - time synchronisation (sampling rate 20-50 Hz),

149 vertical force (e.g. determined from body weight and load weight),

150 foot pressure distribution measuring system (e.g. manufactured by novel GmbH, Munich),

151 amplifier.

The method for determining the load picked up or the externally exerted forces is presented as a flow diagram in Fig. 4. Angular velocity and angular acceleration are calculated for each sampling cycle based on the angles measured using the measuring system described in the invention. The ground reaction force is calculated on this basis, taking anthropometric data into account. Finally, the load picked up is determined by comparing the ground reaction force measured by the foot pressure distribution measuring system with the ground reaction force calculated based on the body angles.

Figure 5 provides a schematic representation of the method for assigning measured postures and load weights to predetermined values and their further processing. In a further stage, the results obtained can be extended to include medical assessments, e.g. statements concerning necessary changes to the activities examined.

Figure 6 shows the flow diagram for calculating the load on a joint or the spine based on the measured time characteristics for body angles (angular velocity, angular acceleration), the measured ground reaction forces, the idealised points of force application and anthropometric data (height, weight, position of centres of gravity).

Total force due to weight is reconstructed on the basis of ground reaction force (measurement) and ground reaction force (model prediction) characteristics. Ground reaction force can be determined from the pressure distribution of the right/left measuring soles. In order to determine force due to weight (body and load weight) and its distribution over the soles of the feet, a commercial foot pressure distribution measuring system (e.g. novel GmbH, Munich) with a portable microcomputer and memory unit 11 is used which

controls the synchronous sampling of the body angles via a synchronising pulse with the measuring system described above. The data stored are evaluated automatically, as described below, once measuring has been completed.

In order to calculate the expected total ground reaction force, the acceleration and velocity components are calculated from the derivatives of the measured body angles and the calculated values transformed into individual joint forces and individual joint moments.

The flow diagram in Figure 7 illustrates a further way in which the measured values can be used, by comparing standard values with the body angles determined and the angular velocities and accelerations calculated, from which it may be possible to conclude any functional limitations.

The following describes the automated recording of vertebral loads based on the example of an occupational activity. An overview of the method for the recording, presentation and automatic classification of biomechanical load variables can be seen in Figure 9.

The time characteristic of body angles is measured in stage a of Figure 9. Details are explained in the following diagrams 10 and 11.

Parallel to this, the ground reaction force and the points of force application in the sole region are measured in stage b.

The results of measurements in stages a and b are utilised firstly, following ergonomic assessment (stages ca1 and ca2), as a load profile of the occupational activity (stage da) and secondly, following biomechanical evaluation in stages cb1 and cb, to present the time characteristic of the disc compression force (stage db). Further block diagrams were created for the ergonomic assessment (Figure 12, Figure 13) and biomechanical evaluation (Figure 14).

Signal conditioning in stage a is presented in the diagram in Figure 10. The following signals are input as electrical measured values into a calibration stage 20 which consists of multipliers, adders and memory units: left and right knee angle signal 21a, 21b, left and right hip angle signal 22a, 22b, leg torsion signal, leg lateral flexion signal 22, 23. The signals 21 - 23 represented by the continuous line were measured with a potentiometer and are therefore relative values; the signals 24 - 30 represented by the dotted line were measured with gyroscopes or inclinometers and therefore constitute absolute angle signals as explained further below. After passing through the calibration stage 20, these absolute signals are input via signal lines 31 - 34 into a signal mixing unit 35 comprising integrators, adders and multipliers. Following the numerical integration of the gyroscope signal for trunk flexion (signal 25), the corresponding inclinometer signals 26, 27 are admixed during each sampling period. The procedure is the same for the trunk flexion angle for the thoracic spine: following numerical integration, the gyroscope signal 28 is continually added to the inclinometer signal 29, 30 during each sampling period. This produces two stabilised signals, thoracic spine (TS) flexion angle signal 36 and lumbar spine (LS) flexion angle signal 37.

These signals 36 and 37 are either input directly into stage cb1 for calculating individual joint forces and individual joint moments, or they are used as signals 38, 39 to convert the relative body angle measurements into absolute angle information 21 - 23.

In addition, interference and noise are removed from the signals 41, 42, 43, 44, 45 taken from the calibration stage 20 in filter unit 40. This is achieved with the aid of usual electronic components, consisting of fast Fourier transform 46, multiplication with low-pass filter function 47 and inverse transformation 48.

Following this procedure, the filtered signals 51, 52, 53, 54 enter the conversion unit 50 where the relative angle signals are converted into absolute spatial angle signals 55, 56, 57 related to a vertical axis. The results can then be examined in stage ca1 to identify motion patterns.

Figure 11 provides a schematic representation of the operating principle of the signal mixer 35. Gyroscope signal 25, which indicates a trunk flexion (lumbar spine), serves as an input signal. Inclinometer signals 26, 27 are marked on the partial section of signal mixer 35 as further input signals. Signal 26 represents the inclinometer range of the lumbar spine in the spatial range 0 - 120° and signal 27 represents the inclinometer range of the lumbar spine from 120 - 240°. Signals 28, 29 and 30 are mixed with gyroscope signal 25 in the same way for the thoracic spine.

The most important element of the signal mixer 35 is the central unit 60, which comprises a memory 61, a sampling interval unit with the sampling frequency f_A and the mixing factor units K_1 for the gyroscope signals 63 and K_2 for the inclinometer signal 64. $K_1 + K_2 = 1$. Preferred values are $K_1 = 0.9$ and $K_2 = 0.1$.

Signal mixing takes place in the central unit 60 according to the function

$$\Phi\,(I) = (\Phi(I-1) + \omega_{gyro}(I) \bullet (f_A)^{-1}) \bullet K_1 + \Phi_{incl}\,(I) \bullet K_2$$

with signal lines 65, 66, 67 directed to the multipliers 68a, 68b and the adder 69. The continual addition of the inclinometer signals 26 and 27 via the adder memory unit 70 produces a stabilised angle signal Φ which is used for both the ergonomic assessment in stages ca1, ca2 and for the biomechanical evaluation in stages cb1, cb2. It is only possible to make statements regarding motion patterns, externally exerted forced and the expected total ground reaction force if measured body angles with spatial reference (in this case, related to the vertical spatial axis) exist.

According to Figure 9, threshold values for identifying motion patterns are formed in stage ca1 and the externally exerted forces determined in stage ca2. Stage ca2 receives the following body angles with spatial reference via line 71 (cf. Fig. 13):

trunk torsion line 72

trunk lateral flexion line 73
trunk flexion LS line 74
trunk flexion TS line 75
hip angle left/right line 76
knee angle left/right line 77.

According to Figure 13, differentiator 80 summarises these body angles into three signal units 81, 82, 83 for the trunk region, the hip region and the knee region, with angular velocities and angular acceleration values also determined for the respective angles. The data from an anthropometric data memory 90a, which contains the dimensions of the test person, such as height 84, weight 85, sex 86, age 87, and the anthropometric database 90b which contains standard body data, such as weight and dimension of parts of the body, position of the centres of gravity of parts of the body and type of joints, are read into the memory 90c via line 88 and 89 respectively. An exchange with the measured data register 91 via line 92 makes it possible to determine the expected total ground reaction force without taking account of externally exerted forces. This total ground reaction force F_{mod} can be retrieved via line 93.

Figure 12 shows how threshold values are determined according to stage ca1 and the output of the load profile in the form of motion patterns and externally exerted forces. A memory 100 which contains the body angle threshold values for the clear characterisation of postures can be considered the central unit here. The memory 100 is connected to a comparator 101 into which the body angle signals with spatial reference, such as trunk torsion 102, trunk lateral flexion 103, trunk flexion LS 104, trunk flexion TS 105, hip angle left/right 106, knee angle left/right 107, are also fed. The comparator 101 is then connected to a memory 108 for the back posture numerical code and a memory 109 for the leg posture numerical code. Both memories are connected via lines 111, 112 to the limit comparator 110 into which a line 113 leads from the comparator 114. The comparator 114 compares the total ground reaction force from line 93 with the load weight classes contained in memory 115. In this way,

load profiles in the form of motion patterns and externally exerted forces can be called up in the limit comparator 110 via lines 116, 117.

In order to determine individual joint forces and moments and the disc compression force in stages cb1 and cb2, the measured body angles must be converted into body angles with spatial reference in accordance with stage a in Figure 9 or Figures 10 and 11. These are described in Figure 14 as signal group 119. Once the corresponding angular velocities and angular accelerations have been determined in differentiator 120, the results are passed onto the multiplier 124 via signal lines 121, 122, 123.

Parallel to this, following the input of the test person's body data via signal group 125, values for the functional muscle anatomy are input via line 127 and for the dimensions, weights of parts of the body, position of centres of gravity of parts of the body and type of joints via line 128 into the central memory 130 with the aid of an anthropometric database 126. Data is exchanged via line 129, with joint forces, joint moments and disc compression forces being passed onto the process stages da, db via line 131.

The results of the process stages da and db are presented by way of example in Figure 15 and Figure 16.

Figure 15 shows an extract from a sequence of movements using the OWAS colour bar representation and corresponding interpretation. The activity sequence can be seen from the time t = 0 s in the following order: standing upright, picking up a load weight (12 kg) with the trunk and knees bent, holding the load, bending the knees with the load, holding the load, putting down the load with the trunk bent and twisted and the knees bent, standing upright. The signals 116, 117 and 93 are fed into the process stage da. Signal 116 contains an angle value corresponding to the applicable OWAS code. Signal 117 indicates the respective load peaks, signal 93 indicates the expected total ground reaction force F_{mod} as a characteristic quantity, without taking account of the externally exerted forces.

The result of the process stage db is a representation of the time characteristic of the disc compression force as a load indicator for stacking heavy boxes. This can be presented, for example, in the form of Figure 16 as a prediction of the L5/S1 disc compression forces. Feedback is also possible to the process stage da via line 132 which means that an overall assessment can be displayed in a single diagram. In this case it is particularly useful to supplement the visual representation with the "vector man" which makes it possible to verify the measured posture data in real time on the screen or the load profile printout. Figure 15 includes code designations and Figure 16 a "vector man" representation.

CLAIMS

1. Method of monitoring biomechanical load variables on a freely moving test person, characterised by:

a) Measuring time characteristics of body angles, including knee angle, hip angle and torso angle with trunk twisted, lateral flexion and large flexions in the region of the thoracic and lumbar spine on a freely moving test person during a physical activity;

b) Measuring ground reaction forces and points of force application to the test person;

ca1) Determining threshold values for the identification of postures and comparison of such threshold values with the measured angles to identify motion patterns;

ca2) Calculating the expected total ground reaction force based on the measured body angles together with the corresponding anthropometric data and subtraction of the expected total ground reaction force from the actual measured total ground reaction force to determine externally exerted forces;

da) Identifying motion patterns and the output of load profiles by monitoring posture and externally exerted forces with time classification throughout the measuring period;

cb1) Deriving acceleration and velocity components of the measured body angles and converting these into individual joint forces and joint moments, taking account of the measured ground reaction force;

cb2) Deriving an intervertebral disc compression force; and

db) Presenting a time characteristic of the disc compression force as a load indicator.

2. Method according to claim 1, wherein the ground reaction force is measured capacitively and the measuring signal is passed on via an amplifier operating on AC voltage to an analog-to-digital converter.

3. Method according to one of the above claims, wherein the ground reaction force is determined based on pressure distribution in across the sole of footwear worn by the test person.

4. Method according to one of the above claims, wherein in order to calculate the expected total ground reaction force, the individual joint forces are determined based on the individual weights and the measured kinematics of the corresponding body parts, and their vertical components are added up.

5. Method according to one of the above claims, wherein the data measured on the test person in stage a) and b) are stored temporarily and, at the same time, pre-processed within a time interval which extends up to the end of the measuring period (e.g. one work shift) for evaluation in accordance with stage ca1, ca2, da, cb1, cb2 and db.

6. Method according to one of the above claims, wherein the measured data are output in the form of a "vector man" representing the sequence of motions.

7. Method according to one of the above claims, wherein the measurements are calibrated by comparing the posture of the test person with the "vector man" at the start and the end of a measuring series.

8. Method according to one of the above claims, wherein, in order to determine the compression force in the region of the lumbar vertebrae, the individual joint forces are determined taking account of the relevant lever arms, and then the compression force acting on the horizontal cross-section of the intervertebral disc is determined based on the moment equilibrium around the centre of gravity of the intervertebral disc.

9. Method according to one of the above claims, wherein, for the determining angles related to the vertical axis, the large flexion angles in the regions of the thoracic and lumbar vertebrae are formed from a combined signal of the inclination velocities measured by gyroscopes and the inclination angles measured by inclinometers.

10. Method according to one of the above claims, wherein further body angles are measured and related to the vertical axis; angle and velocity signals are measured with a sampling rate of 10 - 100 Hz.

11. Method according to one of the above claims, wherein the body angles are determined from relative potentiometer, goniometer and/or inclinometer measurements.

12. Method according to one of the above claims, wherein, in order to stabilise the large flexion angle, a combined signal comprising the numerically integrated gyroscope signal to which the inclinometer signal is continually added is produced during each sample.

13. Method according to one of the above claims, wherein the individual values, which are measured by the gyroscope and inclinometer sensors and the potentiometers and converted to the vertical axis, are subtracted from the threshold values and the difference is used to identify a motion pattern.

14. Method according to one of the above claims, wherein the measured body angles are transformed into motive forces by determining the velocities and acceleration based on the mathematical derivatives of the measured angles and calculating the joint forces and the joint moments acting on the centre of gravity, taking account of the joint type, the respective position of the centre of gravity and the forces due to weight of the parts of the body concerned.

15. Method according to one of the above claims, wherein the expected total ground reaction force is determined based on the measured body angles (angular velocity, angular acceleration) and the anthropometry (size, weight, position of centres of gravity) of the parts of the body.

16. Method according to one of the above claims, wherein the load peaks are determined based on the measured forces due to weight and compared with a peak dose (force-time-load).

17. Method according to one of the above claims, wherein the threshold values are defined as positive or negative angle variables and that, if these are exceeded or undercut, a signal is triggered to identify a movement.

18. Monitoring system for recording biomechanical load variables, especially for recording posture and body movement, characterised in that such system comprises a plurality of angle sensors to be attached to joints, including knee and hip joints, and the spine of a freely moving test person, an energy supply source and means for monitoring and recording electronic signals generated by combinations of sensors, each comprising two inclinometers and one gyroscope, to measure the position of the spine in relation to a fixed vertical axis at at least two points.

19. Monitoring system according to claim 18, wherein two inclinometers are used so that an angular range greater than 180° can be covered.

20. Monitoring system according to claim 18 or 19, wherein an evaluation unit is provided for weighting the output signals it receives from the inclinometers and the gyroscope and summarising them as a single value.

21. Monitoring system according to one of claims 18 to 20, wherein the evaluation unit for weighting the output signals it receives comprises an electronic arrangement for processing the signals, consisting of integrator and adder operational amplifier circuits.

22. Monitoring system according to claim 20, wherein a foot pressure distribution measuring system is provided for recording the ground reaction force with the same sampling rate as the posture equipment.

23. Monitoring system according to claim 22, wherein equipment is provided for the synchronous sampling of the posture sensors and the foot pressure distribution measuring system.

24. Monitoring system according to claim 20 or 23, wherein the knee angle sensors (1), preferably potentiometers, are mounted on rails (2) which can

be attached to the lower leg over the clothing and adjusted in relation to the position of the knee joint.

25. Monitoring system according to claim 24, wherein the hip angle sensors (4), preferably potentiometers, are mounted on moulded plates (6) which can be attached to an adjustable hip belt (7) to be worn over the clothing and which can be adjusted as required in relation to the position of the hip joints.

26. Monitoring system according to claim 25, wherein the hip angle sensor (4) and the knee angle sensor (1) for one side of the body in each case are set in accordance with the test person's posture by means of a flexible connection (5) which can be detached using a quick-release catch (5a).

27. Monitoring system according to claim 26, wherein the sensor combinations on the hip belt (7) for Monitoring the flexion of the lumbar spine are attached in the sagittal plane relative to the vertical axis.

28. Monitoring system according to claim 27, wherein the sensor combinations can be attached to a jacket (9) to be worn over the clothing for Monitoring the flexion of the thoracic spine in the sagittal plane relative to the vertical axis.

29. Monitoring system according to claim 28, wherein an inclinometer is provided for Monitoring the flexion of the thoracic spine in the lateral plane relative to the vertical axis which can be attached to the jacket (9) in the region of the thoracic vertebrae.

30. Monitoring system according to claim 29, wherein a potentiometer for Monitoring the twisting of the spine between the regions of the lumbar vertebrae and the thoracic vertebrae is provided which can be attached to the jacket (9) in the region of the thoracic vertebrae and set via a torsion-free connection (14) to a guide (13) attached to the hip belt (7) in the region of the lumbar vertebrae which is used to adapt to changes in length.

31. Monitoring system according to claim 30, wherein an energy supply source (15), a microcomputer unit (10) for activating and scanning the sensors and a memory unit are attached to the jacket (9).

32. Monitoring system according to claims 23 and 31, wherein equipment is provided for determining the load handled based on the posture and ground reaction force data registered by the Monitoring system.

33. Monitoring system according to any one of claims 18 to 32, wherein the equipment for determining the load handled consists of a control system into which the registered posture and ground reaction forces are entered as the input signal and the calculated ground reaction forces as the reference variable.

34. Monitoring system according to any one of claims 18 to 33, wherein equipment is provided for the continual comparison of the determined posture and load weight data with and their assignment to predetermined postures and load weights and their weighting.

35. Monitoring system according to any one of claims 18 to 34, wherein equipment is provided for determining forces acting on certain parts of the skeleton, especially the spine, and their time characteristic based on the determined posture and load weight data using a dynamic model of the human body.

36. Monitoring system according to any one of claims 18 to 35, wherein equipment is provided for comparing the determined chronological and spatial motion patterns of joints or the spine with specified standard values in order to establish functional limitations.

37. A method according to claim 1, and substantially as herein described.

38. A monitoring system according to claim 1, and substantially as herein described.

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UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1N(NACNH) G1N(NEAX, NENX)

Int Cl (Ed.6): A61B (5/103, 5/11, 5/22)

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0 494 749 A1	(Orthopedic Systems Inc.)	
A	WO 98/03110 A2	(Curchod)	
A	WO 95/32666 A1	(Curchod)	
A	WO 89/01760 A1	(Nyberg)	
A	WO 87/00026 A1	(Nilsson)	
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